"Medical advances may seem like wizardry. But pull back the curtain, and sitting at the lever is a high-energy physicist, a combinational chemist or an engineer. Magnetic resonance imaging is an excellent example. Perhaps the last century’s greatest advance in diagnosis, MRI is the product of atomic, nuclear and high-energy physics, quantum chemistry, comscience, cryogenics, solid state physics and applied medicine."

Harold Varmus, Nobel Laureate in Medicine (Washington Post, 2000)
The Role of CERN for Health Issues

M. Winter (IPHC/CNRS – Strasbourg/France)

Athens / 17 April 2016

Contents

• What is CERN ?
• Technology & methodology developed for CERN’s physics programmes
• Impact on health care
• CERN’s actions for health care
• Concluding remarks and Outlook
What is CERN?
What is CERN?

- CERN was founded in 1954
- Name comes from "Conseil Européen pour le Recherche Nucléaire" (1952)
- Today: about 2500 staff scientists, engineers and administration agents and more than 10,000 non-permanent people on site
- Originally 12 membre states → 21 membre states today
The twenty one Member States of CERN
Les vingt et un Etats membres du CERN
Member States (Dates of accession)
Etats membres (Dates d’accession)
- Austria (1959)
- Belgium (1958)
- Bulgaria (1959)
- Czech Republic (1993)
- Denmark (1956)
- Finland (1963)
- France (1952)
- Germany (1957)
- Greece (1957)
- Hungary (1952)
- Israel (2002)
- Italy (1953)
- Netherlands (1954)
- Norway (1953)
- Poland (1961)
- Portugal (1968)
- Slovakia (1995)
- Spain (1958)
- Sweden (1959)
- Switzerland (1963)
- United Kingdom (1954)
Hosts Scientists from all over the world

Largest Academic Research Center on Earth

CERN Membre States
Official Mandate of CERN

- Conduct research in Particle Physics for Europe (membre states)
- Develop infrastructure required for its research program
  - Accelerators
  - Detectors
  - Computing
- Foster research in Particle Physics in Europe
  - On-site academic support (Summer student program, academic training, ...)
  - Host headquarters of international particle physics experiments
  - Organise or host particle physics conferences and workshops
  - Explain particle physics to public: purpose, achievements, prospects
- CERN’s activities followed up & supervised by CERN Council
  (2 membres per State)
What is Particle Physics About?

- Particle physics: one of the greatest achievements of mankind
  addresses the question of the **ORIGIN**

- Research follows reductionist paradigm driving evolution of science since Galileo, Descartes, Newton, ...:

  "No understanding is complete unless it also incorporates an understanding of its constituents"

- Particle physics probes the nature of fundamental particles and of the space between them, with two main outcomes:
  - a steadily clearer view of Nature’s components and their interactions
  - a steadily clearer view of the origin and history of Universe
Chart of Elementary Particles
What is Particle Physics About?

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- This goal calls for revolutionnary concepts and innovative technologies:
  
  - Particle physicists and research engineers invent their own tools
  - They transfer their technological innovations to other fields, including industry
  - They also transmit their conceptual inventions to society
    - Anti-matter, Big Bang, Black Holes, etc.
Example of Long Range Impact of Particle Physics on Society

The Dirac equation in the form originally proposed by Dirac is:

\[
\left( \beta mc^2 + \sum_{k=1}^{3} \alpha_k p_k c \right) \psi(x, t) = i\hbar \frac{\partial \psi(x, t)}{\partial t}
\]

Quadratic equation in particle’s energy: solution expressed by \(E^2\)

\(\Rightarrow\) 2 solutions for \(E\): \(E > 0\) and \(E < 0\) (forbidden by classical physics)

\(\Rightarrow\) Particle: electron (\(E > 0\))

Anti-particle: positron (\(E < 0\)) \(\rightarrow\) like electron with opposite electric charge

1932: Discovery of positron by Anderson

Today: Electron-Positron Tomography (EPT) exploits electron-positron annihilation for health diagnosis (typical signature: 2 back-to-back photons with energy = electron mass)
In 1928, British physicist Paul Dirac wrote down an equation that combined quantum theory and special relativity to describe the behaviour of an electron moving at a relativistic speed. The equation which won Dirac the Nobel prize in 1933 posed a problem: just as the equation $x^2 = 4$ can have two possible solutions ($x = 2$ or $x = -2$), so Dirac’s equation could have two solutions, one for an electron with positive energy, and one for an electron with negative energy. But classical physics (and common sense) dictated that the energy of a particle must always be a positive number.

Dirac interpreted the equation to mean that for every particle there exists a corresponding antiparticle, exactly matching the particle but with opposite charge. For the electron there should be an "antielectron", for example, identical in every way but with a positive electric charge. The insight opened the possibility of entire galaxies and universes made of antimatter.

But when matter and antimatter come into contact, they annihilate, disappearing in a flash of energy. The big bang should have created equal amounts of matter and antimatter. So why is there far more matter than antimatter in the universe?
Large Hadron Collider
Particle Accelerators

- Deep understanding of particle beam physics
- Development of high intensity particle sources
  - ordinary particles: electrons, protons, X-Ray, ...
  - specific particles: positrons, neutrons, ions, ...
- Develop new generation acceleration technics
  - klystrons = energy sources
  - supra-conducting accelerating cavities with ever higher accelerating gradients (plasma)
- Develop particle transport systems
  - vacuum systems
  - magnetic elements: dipoles, sextupoles, ...
- Develop particle beam focusing systems
  - supra-conducting quadruples
  - nanometres large beams
- Develop beam control/monitoring systems
  - non-destructive beam diagnosis based on particle detection
  - fast high-precision feedback (correction) systems
Next Generation of Accelerator

klystrons: \( \simeq 4,000 \) components
Particle Detectors

- Deep understanding of particle-matter interactions
- Deep understanding of detection systems and techniques
- Development of detectors adapted to various particle types:
  - charged particles: electrons (incl. bêta particles), protons, muons, ions
  - neutral particles: photons (incl. X-Rays), neutrons
- Development of detectors using various detection modes:
  - tracking for charged particles: semi-conductor, gas, scintillators
  - calorimetres (absorbing): glas, iron, liquid, etc.
- Highly integrated and fast signal generation, filtering & transformation:
  - High performance signal generation and processing systems
  - Fast, large bandwidth, signal transmission systems: electrical, optical
  - Sophisticated signal filtering systems
An Experiment at LHC: the ATLAS Detector

- Dimensions: 46 metres long, 25 meters diameter
- Contains some 3,000 km of cable
- Weight: 7,000 tons
- Collaboration: 3,000 physicists from over 175 institutes involving 38 countries
- Together with the CMS experiment, ATLAS discovered in 2012 a new particle, consistent with the long awaited Higgs boson
Information Handling

- **Information treatment:**
  - fast and large bandwidth communication networks
    - Web invented at CERN in 1989
  - optimal-reinforced use of software resources
    - Computing grid developed by CERN’s community
  - analysis strategies adapted to detailed signal features swamped by humongous background

- **Capability to handle and develop complexity**

- **Capability to transmit knowledge and expertise:**
  - network with universities (students)
  - synergy with industry (transfer of high-tech knowledge)

- **Capability to attract other main actors of society:**
  - medical community
  - space scientists
  - accelerator industry
"State-of-the-art techniques borrowed from particle physics accelerators and detectors are increasingly used in the medical field for the early diagnosis and treatment of tumors and other diseases. Yet medical doctors and physicists lack occasions to get together and discuss global strategies."

The Physics for Health in Europe workshop at CERN in 2010 represented one of the first attempts to develop synergies between the particle physics and medical communities.

The conference welcomed more than 400 participants from 32 countries.

It was the beginning of the ENVISION & ENLIGHT programs.
Hadrontherapy is a highly advanced technique of cancer radiotherapy that uses beams of charged particles (ions) to destroy tumour cells.

In order to improve the quality assurance tools for hadrontherapy, the European Commission has funded ENVISION, a 4-year project that aims at developing solutions for:

- real-time non-invasive monitoring
- precise determination of delivered dose
- quantitative imaging
- fast feedback for optimal treatment planning
- real-time response to moving organs
- simulation studies

Launched in February 2010, ENVISION is a collaboration of sixteen leading European research centres and industrial partners, coordinated by CERN.

ENVISION also serves as a training platform for the Marie Curie Initial Training Network ENTERVISION.

ENVISION and ENTERVISION are under the umbrella of ENLIGHT, the European Network for Light Ion Hadron Therapy.
An Example of Differenciated Particle-Matter Interaction

- X-Rays (photons in general) deposit energy all long their path in the body
  → they are destructing numerous healthy cells over the full X-Ray range

- Ions (protons, carbon ions) deposit about 80% of their energy near the end of their path
  → they are destructing much less healthy cells than X-Rays

- The "Bragg-peak" depth is a function of the beam energy, which can be modulated according to the tumor position and extension (dimensions)
Particle therapy centres in Europe - 2015

Source: PTCOG, October 2015
CNAO (Centro Nazionale di Adroterapia Oncologica)
Physics for Health: CERN asked to take up 3 Tasks

- First Physics for Health workshop organized at CERN in February 2010
  - Recommendation that CERN be involved in three innovative projects

- CERN in charge of 3 actions:
  - new research facility for biomedical uses
  - launch new study for a compact and low-cost accelerator for hadrontherapy
  - create a European distributed user facility for the production of innovative radioisotopes
Recent Workshop organised by CERN

INTERNATIONAL CONFERENCE ON TRANSLATIONAL RESEARCH IN RADIATION ONCOLOGY | PHYSICS FOR HEALTH IN EUROPE

February 15 – 19, 2016 CICG, Geneva, Switzerland

Abstract submission and early registration deadline: Oct 31, 2015
Late registration deadline: Jan 18, 2016

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P. Lambin, Maastricht
B. Wouters, Toronto

NUCLEAR MEDICINE
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O. Ratib, Geneva
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Public Seminar: Feb 16, 2016 18:30
Industrial Exhibition: Feb 15 – 19, 2016
ICTRPHE-exhibitor-sponsor-support@cern.ch

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UNITING PHYSICS, BIOLOGY AND MEDICINE FOR BETTER HEALTHCARE

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Concluding Remarks – Outlook

- Particle Physics: forerunner of tomorrow’s concepts & technologies
- Deals with specific (non-intuitive) concepts impacting society in depth
- Essential for tomorrow’s health care technological progress
  - accelerators
  - detection techniques
  - methodologies
- CERN = major player in this game worldwide: has become pillar for health care issues in close connection with medical experts
- Particle physics has numerous fundamental questions ahead:
  - Matter-antimatter asymmetry
  - Dark Matter explanation
  - Dark Energy mystery
  - Gravitation
  - etc.
- They are expected to continue providing technology and methodology evolutions extending mankind’s ability to take care of its health
Visit CERN!